Prologue

22 February 2007

14 Uranium Pellets found in a garden

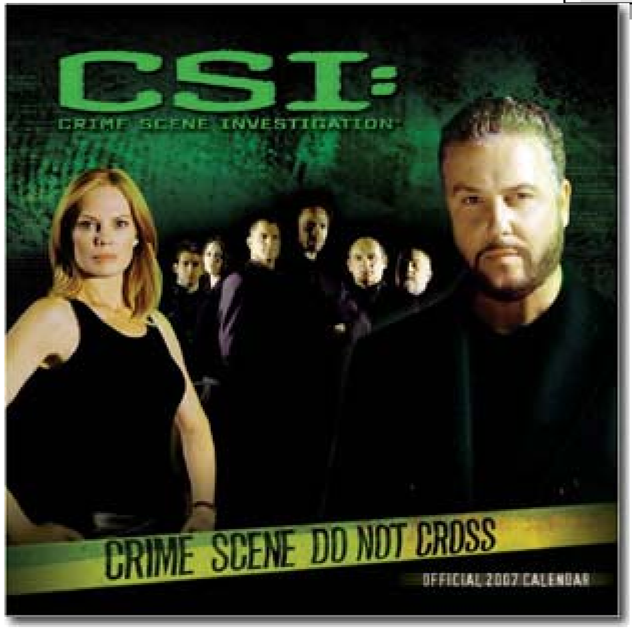
Atomic Detectives at Work: Nuclear Forensics and Illicit Trafficking

Klaus Mayer, Maria Wallenius
Institute for Transuranium Elements (ITU)
Karlsruhe, Germany

http://itu.jrc.cec.eu.int

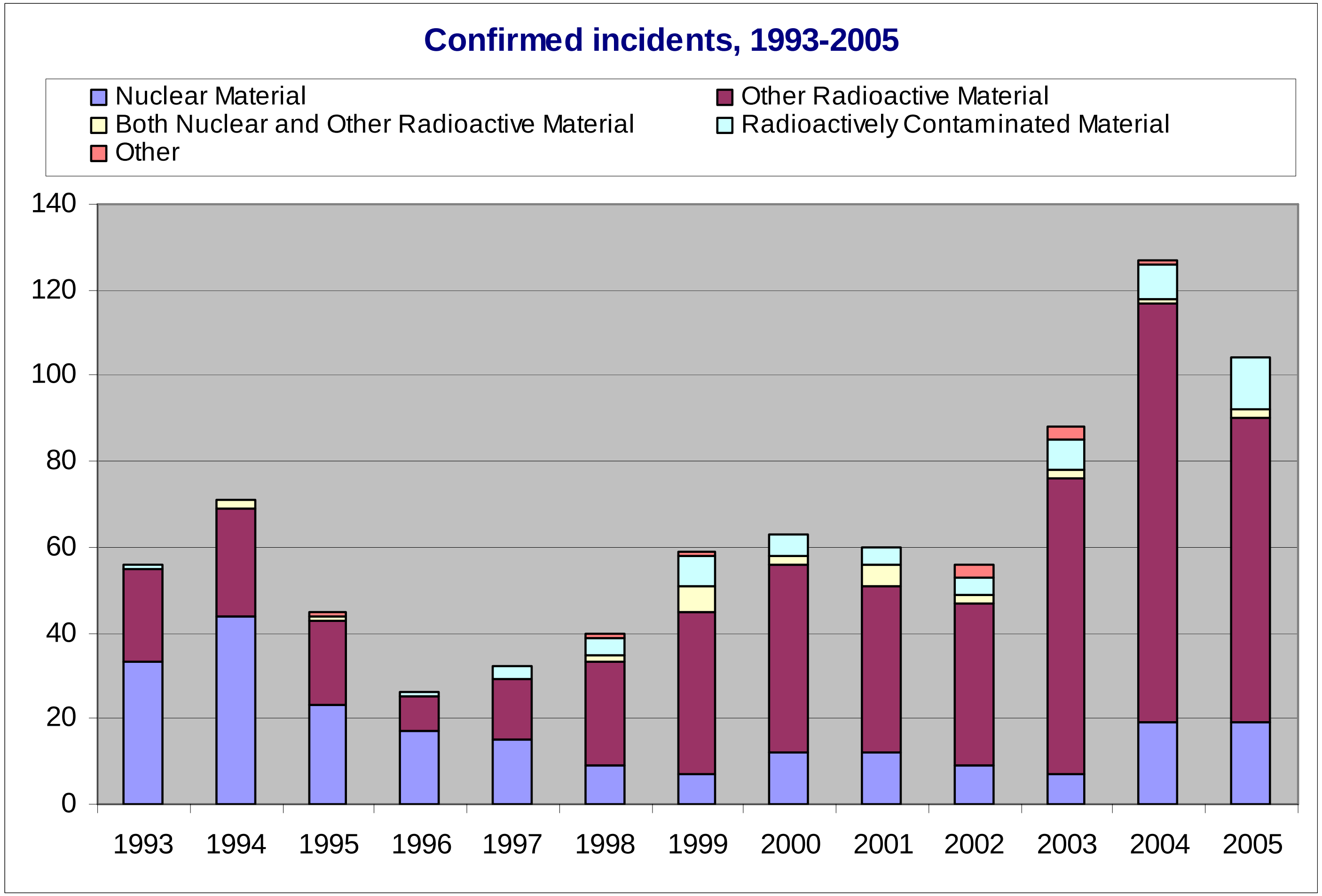
http://www.jrc.cec.eu.int

Introduction



Illicit Trafficking of Nuclear Material

- Traditional Safeguards and Physical Protection fail
- Illicit traffic of nuclear and other radioactive material



Combating Illicit Trafficking of Nuclear Material

Detection

Detection equipment, intelligence

Nuclear Material (U, Pu, reactor or weapons grade) or other radioactive material (^{60}Co, ^{137}Cs, ^{192}Ir,…)

Categorization

Nuclear Forensics

Source Attribution

Sequence of Actions

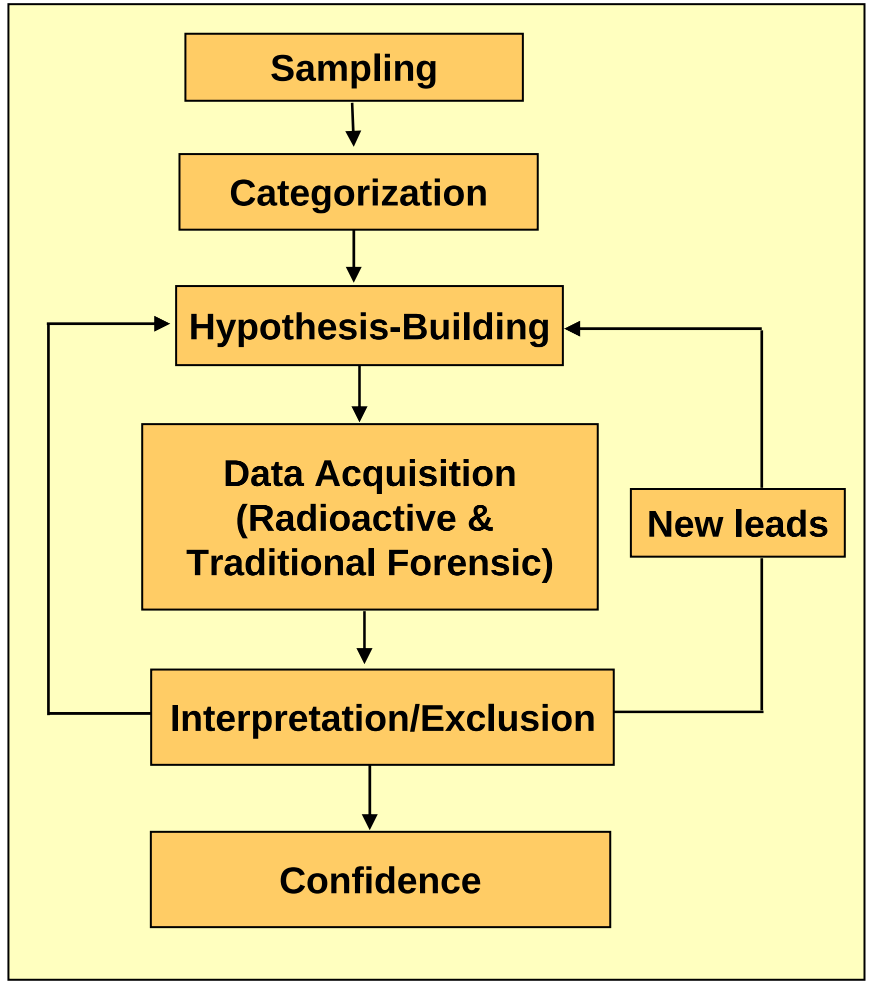
- Securing the Material
- Preservation of Evidence

Signature Development

Empirical studies on the physical structure, isotopes, and chemistry of nuclear materials
- Link interdicted samples to routes and individuals

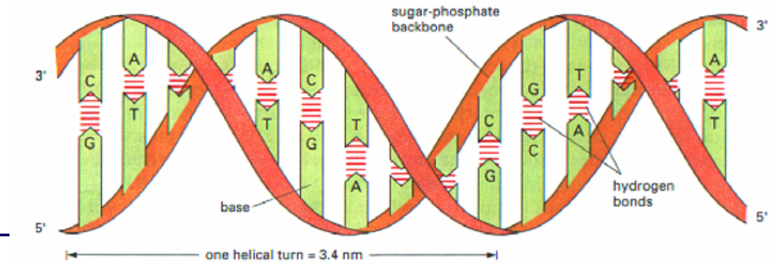
Knowledge Management

Ready comparison of analytical signatures against known signatures from nuclear production, reprocessing manufacture, and storage



Joint Research Centre

Classical Forensics



Aims at identifying suspect **individual** using information adherent to the pieces of evidence:

- Fingerprints
- **“genetic fingerprint”**
- Fibre
- Hair
- Residues of explosives

Objective

Solve criminal case and put criminal individual to jail

Nuclear Forensics

Aims at identifying origin and intended use
using information inherent to the (nuclear) **material**:

- Isotopic Composition
- Elemental Composition
- Impurities
- Macroscopic appearance
- Microstructure

Objective

Improve safeguards and physical protection measures at place of theft or diversion to prevent future thefts or diversions

Nuclear Forensics Methodology

Analytical Methods taken from:

- Safeguards
- Material Science
- Isotope Geology

→ Data →

- Isotopic Composition
- Elemental Composition
- Impurities
- Macroscopic appearance
- Microstructure
- Age

↓ Information

Exogenic
requires reference data

Place of Production
Last Legal Owner
Smuggling Route

Endogenic
self-explaining

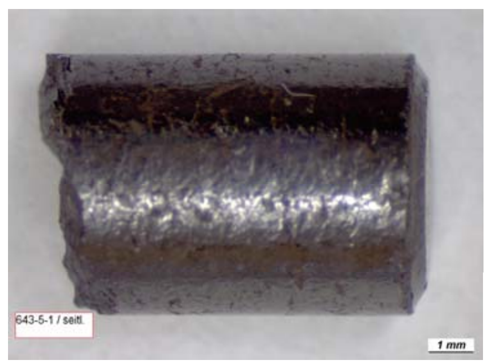
Age
Intended Use
Production Mode

Example 1 – Uranium Pellets

- 3 x 3 pellets (DA, microscopy, archive)

Dimensions

Pellet no.	Weight (g)	Diameter (mm)	Height (mm)
590-1	16,0061	12,33	13,11
590-2	15,6353	12,35	12,69
590-5	17,1390	12,31	14,01
642-1	15,3515	11,43	14,30
642-2	15,9104	11,42	14,88
642-5	15,5325	11,42	14,70
643-1	2,7391	5,81	10,12
643-2	2,7110	5,82	10,08
643-5	2,1489	5,81	8,3

joint research centre

Pellets 590

U-content w-%:	Titration:	**88.10 ± 0.13**
	K-edge:	**87.93 ± 0.33**
	IDMS:	**88.05 ± 0.15**

UO_2

w-%	U-234	U-235	U-236	U-238
HRGS	0,005	0,697	-	99,298
TIMS	0,0049	0,711	-	99,284
MC-ICP-MS	0,0051	0,712	<0,0001	99,283

Age: 16,85 a ± 0,3 (Date of production: end of 1989).

Pellets 590

		Measured	CANDU	BN-350, BN-600 breeding zone
Outer diameter	mm	12.36 – 0.30	12.16	$13.0_{-0.3}$
Inner diameter	mm	-	0.00	0.00
Dish diameter	mm	n/a	exists but value unknown	no dish
Content $^{235}U/^{tot}U$	w-%	0.71	$\geq {}^{nat}U$	< 0.7
Manufacturer			various	MZ Elektrostal
			Possible match	Excluded

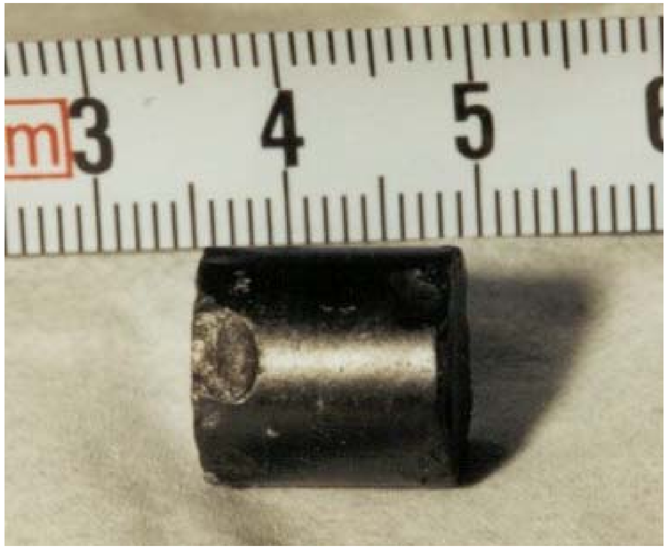
Limited data from open literature (no drawing available).

Intended use (in Europe): Cernavoda-1 in Romania.

Possible place of fabrication: also Romania (plant was shut down in 1992).

Similar finds

- Find 3 - Windsbach 1992: **- 22 nat. U pellets**
- Find 9 - Munich 1993: **- 2 nat. U pellets**
- Find 12 - Mainz 1994: **- 3 nat. U pellets**
- Find 21 - Karlsruhe 1994: **- 1 nat. U pellets**



Pellets 642

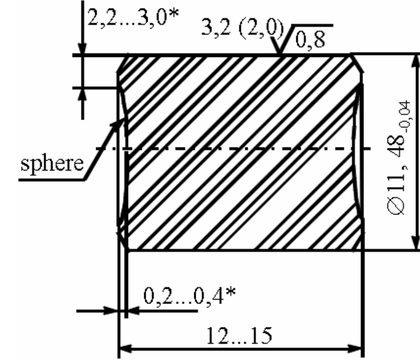
U-content w-%:		
	Titration:	**88.23 ± 0.13**
	K-edge:	**87.83 ± 0.33**
	IDMS:	**88.09 ± 0.15**

UO_2

w-%	U-234	U-235	U-236	U-238
HRGS	0,025	2,506	-	97,469
TIMS	0,035	2,512	0,471	96,982
MC-ICP-MS	0,035	2,514	0,451	97,001

Age: 13,6 a ± 0,2 (Date of production: beginning of 1993).

Pellets 642



		Measured	RBMK-1000	RBMK-1500	RBMK-Er
Outer diameter	mm	**11.45 ± 0.15**	$11.48_{-0.04}$	$11.48_{-0.04}$	$11.48_{-0.04}$
Inner diameter	mm	-	0.00	1.9 + 0.3	1.9 + 0.3
Dish diameter	mm	**6.16 ± 0.10**	6.28 ± 0.80	6.28 ± 0.80	6.28 ± 0.80
Land outer diameter	mm	8.9 ± 0.2	$*10.7_{-1.7}^{+0.4}$	$*10.7_{-1.7}^{+0.4}$	$*10.7_{-1.7}^{+0.4}$
Chamfer height	mm	*0.4 .. 1.2	0.2 .. 0.4	0.2 .. 0.4	0.2 .. 0.4
Content $^{235}U/^{tot}U$	w-%	2.5	2.0; 2.4	2.0; 2.4	2.4; 2.6
Content Er	w-%	-	0.0	0.0	0.41
Manufacturer			MZ Elektrostal **UMP Ulba**	MZ Elektrostal UMP Ulba	MZ Elektrostal
			Possible match	Excluded	Excluded

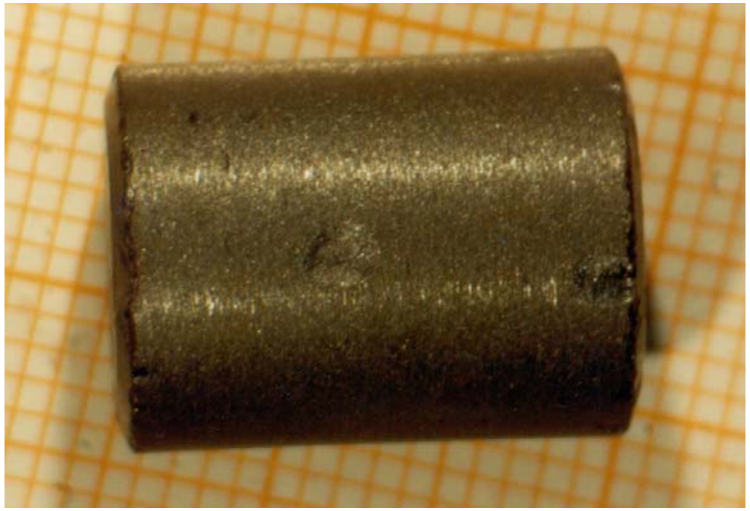
Pellets 642

Intended use: RBMK-1000 (initial enrichment 2,4 %)

- Russia:
  - Kursk 1,2,3
  - Leningrad 1,2,3,4
  - Smolensk 1,2,3
- Ukraine:
  - Chernobyl 1,2,3,4 (accident reactor)

Similar finds

- Fund 1 - Augsburg 1992: **- 72 RBMK pellets (2.5 %)**
- Fund 10 - Waidhaus 1993: **- 1 RBMK pellet (2.5 %)**



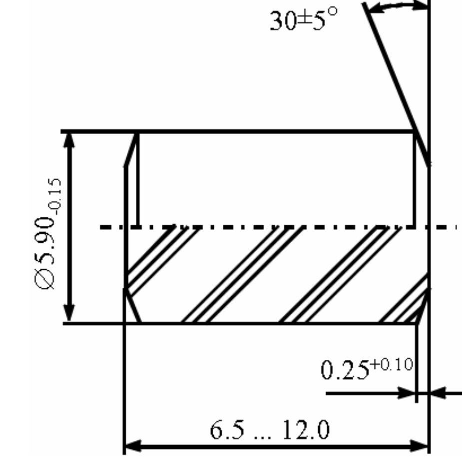
Pellets 643

U-content w-%:	Titration:	**88.14 ± 0.13**
	K-edge:	**87.73 ± 0.33**
	IDMS:	**87.94 ± 0.15**

UO_2

w-%	U-234	U-235	U-236	U-238
HRGS	0,001	0,233	-	99,767
TIMS	*0,0007*	0,255	0,0061	99,738
MC-ICP-MS	0,0013	0,256	0,0054	99,737

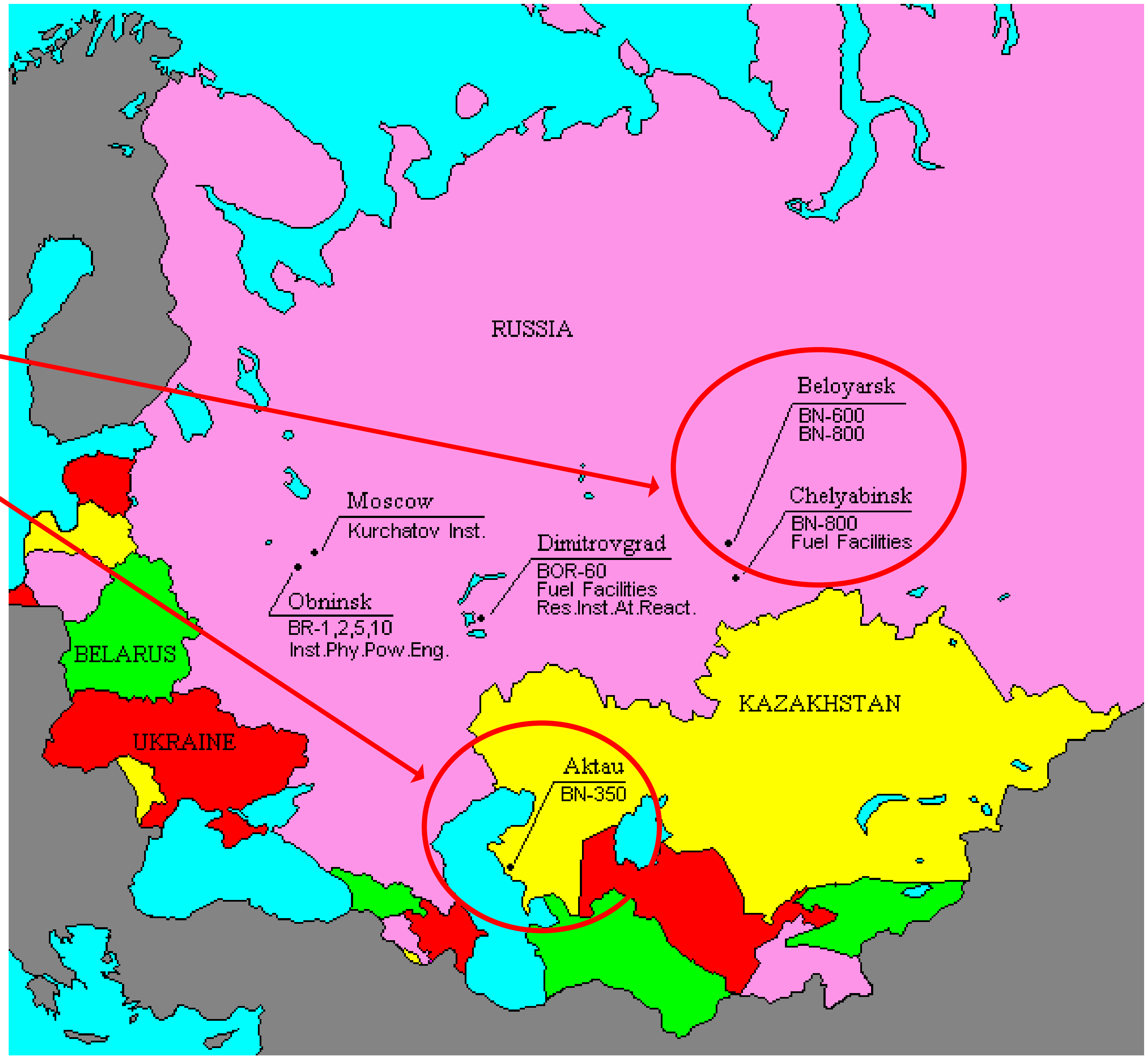
Pellets 643



		Measured	BN-350, -600 screening zone	BN-350, -600 main zone	BN-350,-600 breeding zone
Outer diameter	mm	**5.80 ± 0.06**	$5.90_{-0.15}$	$5.95_{-0.15}$	$13.0_{-0.3}$
Inner diameter	mm	-	0.00	$1.7^{+0.2}$	0.00
Dish diameter	mm	**No dish**	No dish	No dish	No dish
Land outer diameter	mm	**4.55 ± 0.1**	$*5.03_{-0.80}^{+0.15}$	$*5.03_{-0.80}^{+0.15}$	$*10.92_{-1.2}^{+1.7}$
Chamfer height	mm	***0.3 .. 0.6**	$0.25^{+0.10}$	$0.25^{+0.10}$	0.6 ± 0.1
Content $^{235}U/^{tot}U$	w-%	0.26	< 0.7 (depleted)	17; 21; 26	< 0.7 (depleted)
Manufacturer			MZ Elektrostal	MZ Elektrostal	MZ Elektrostal
			Possible match	Excluded	Excluded

Pellets 643

Intended use:



Example 2 Uranium Cube

?

Nuclear Forensics -Examples

Origin and intended use ?

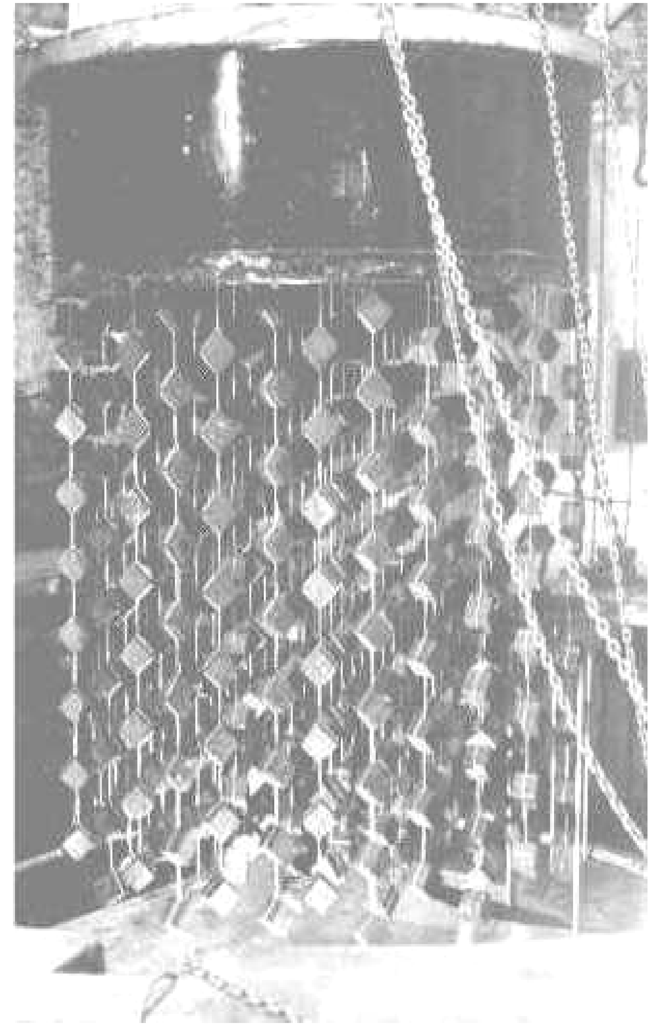
First observations/conclusions:

- geometry → 5 x 5 x 5 cm, unconventional application/reactor
- elemental composition → pure U metal
- isotopic composition → natural U → D_2O or graphite moderated reactor
- main impurities → Al, Ca, (Fe), Mg, Mn, Na, Pb, Si

Nuclear Forensics -Examples

1. Origin

- Nuclear Materials Database
  - – nuclear fuel data from western and Russian suppliers (UO_2, MOX) (based on World Nuclear Industry Handbook and bilateral contracts, various degrees of access)
- Electronic literature archive on non-conventional fuels (Russian sources)
- Open literature →



Geometry points at German origin

Nuclear Forensics -Examples

Joint Research Centre

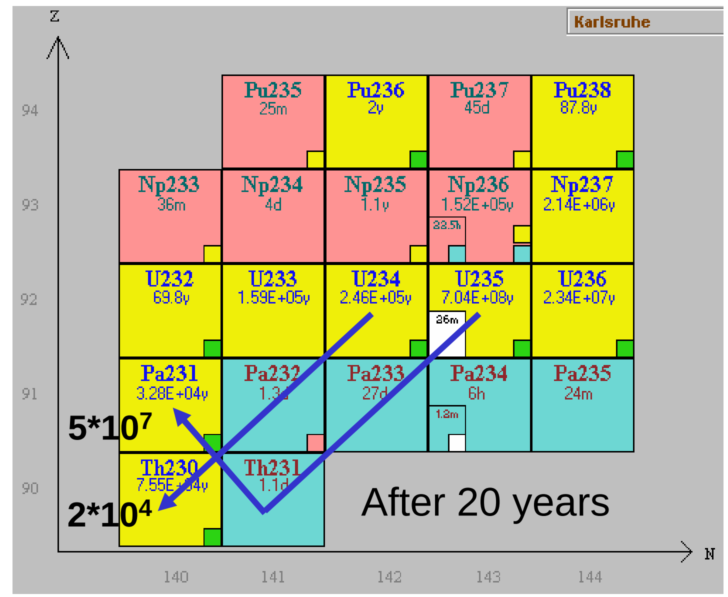
2. Age determination

- spiking with ^{228}Th (or ^{233}Pa)
- chemical separation
- measurement: alpha spectrometry or mass spectrometry

Age via ^{234}U / ^{230}Th

Age by ID-AS: 59.0 ± 1.5 years
=> Date of production: December 1943

Age by ICP-MS: 59.3 ± 2.0 years
=> Date of production: September 1943



Age indicates German (or US) nuclear programme

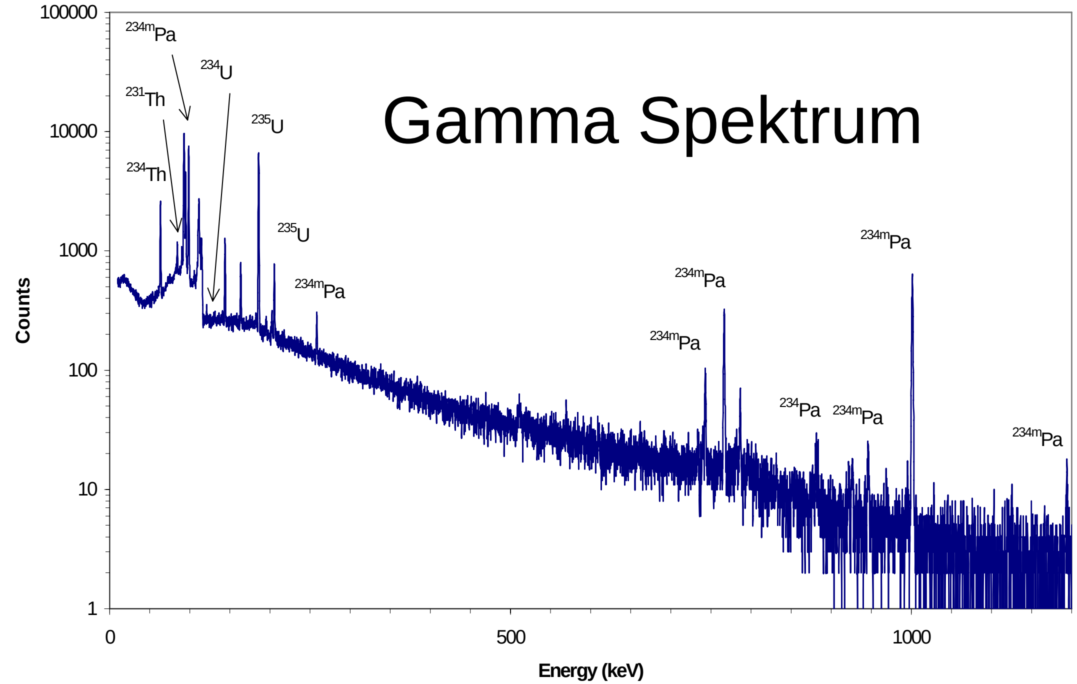
Nuclear Forensics -Examples

Was the reactor operational ?
If yes: U-235 + n → U-236, fission products, ….

3. Nuclidic information

Presence of ... ?

^{236}U, Pu, FP

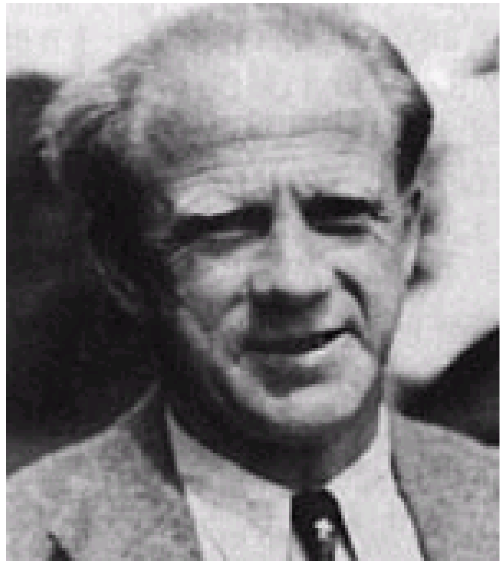


NO SIGNALS (within detection limits)

reactor was not operational

Werner Heisenberg

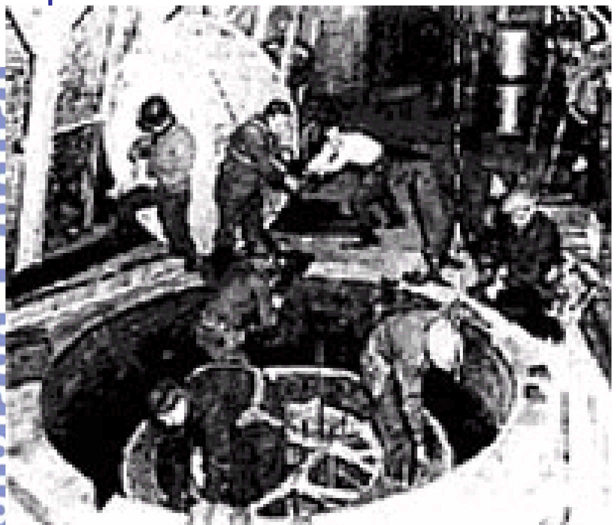
1901 - 1976



- Uncertainty principle 1925
- Professor at University of Leipzig 1927
- Nobel price 1932

- Professor at University of Berlin 1941
- Director of the Kaiser Wilhelm Institute 1942

"Uranium machine"



659 cubes seized by Americans

5 cubes disappeared !!

Example 3 Plutonium Powder

August 10 in 1994, Munich airport

201 g of Li-metal enriched to 89.4 % in ^{6}Li.

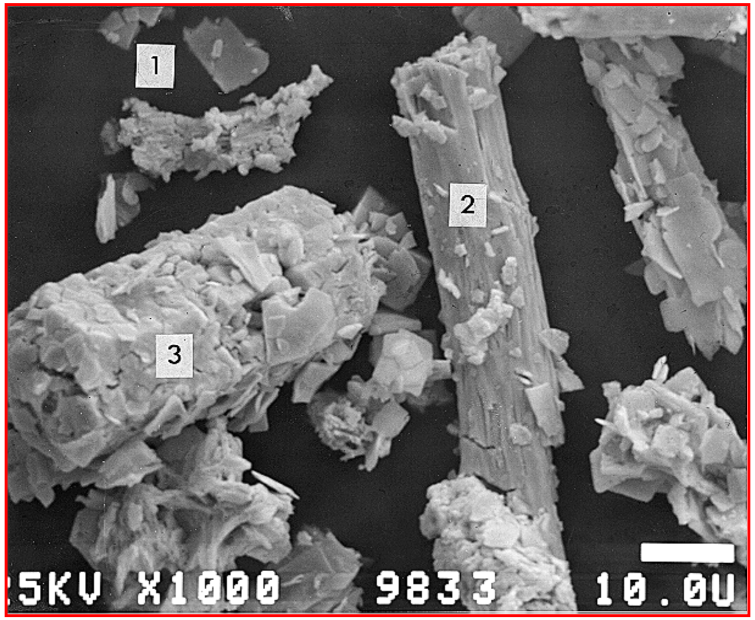
Mixed plutonium and uranium oxides:

363 g Pu - 121 g U

Pu	238	239	240	241	242
w-%	0.17	87.58	10.78	0.81	0.66

U	234	235	236	238
w-%	0.020	1.60	0.048	98.35

Fund 19 - Munich



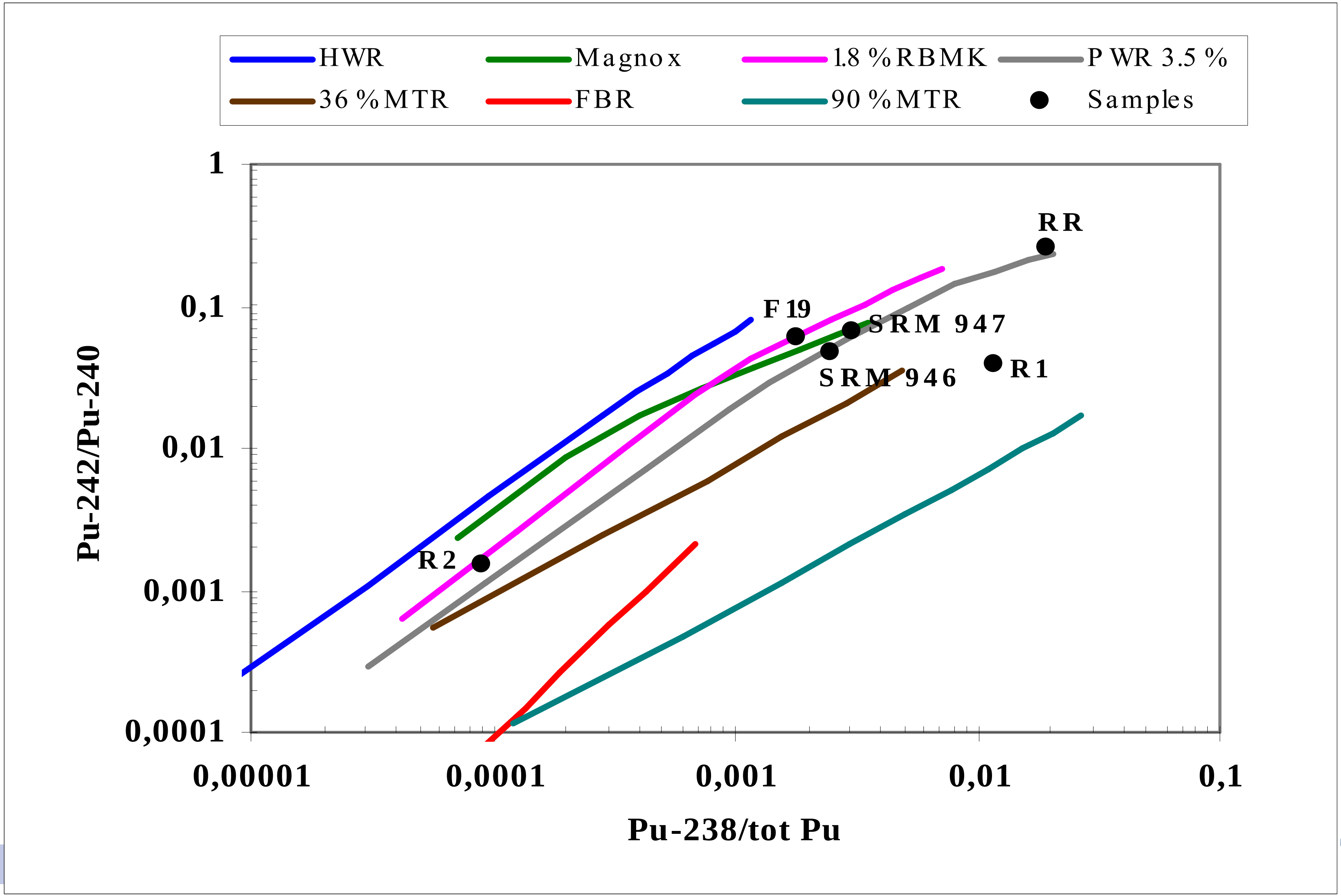
Powder consists of three particle types:

1) platelets of PuO_2 (80 %)
2) rod-shaped PuO_2 (5 %)
3) hexagonal U_3O_8 (15 %)

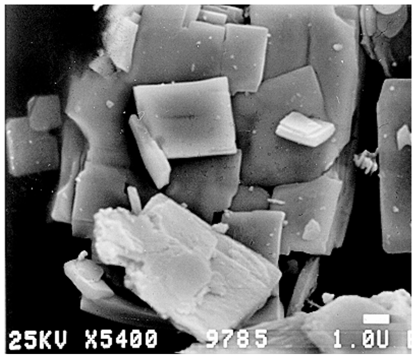
	Bulk	Particle 1	Particle 2
$^{240}Pu/^{239}Pu$	0.1226	0.1159	0.1245
Age from the $^{240}Pu/^{236}U^{*}$	(20.6)**	21.5	19.9

Mode of Production

Plutonium isotopic correlations point at reactor type where the Pu was produced

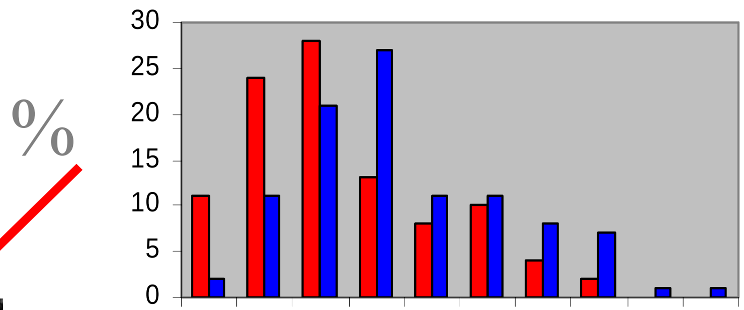


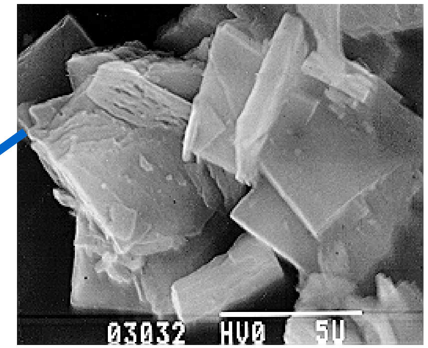
Microstructural Fingerprint



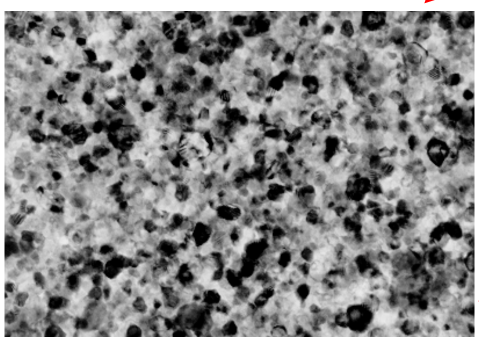
?

SEM

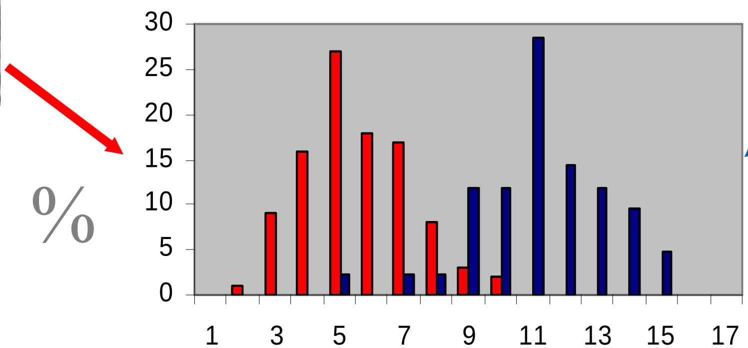


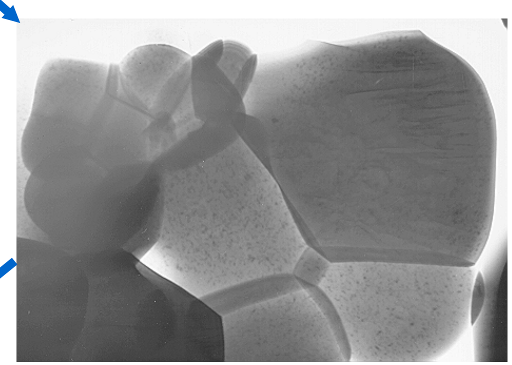


Reference SM3-1



TEM





Classical Forensics on Contaminated Items

- Training
  - Nuclear Forensics Awareness
  - Response Plan
  - Measurement Teams (BfS)
- Cooperation with Police (BKA)
  - Dedicated glove-box for taking fingerprints from contaminated items
  - Procedures for Crime Scene Management
- Emergency Preparedness
  - Modeling the Dispersion of Radioactivity after RDD explosion

Development of a Comprehensive Response

International Cooperation

- Joint training IAEA/ITU on **Response to Illicit Trafficking**
- TACIS Multi-Country Project on Combating Illicit Trafficking (Russia, Georgia, Moldova, Ukraine, Azerbaijan)
- Coordination of Activities with IAEA, US DOE SLD, European Council

- Cooperation Europol and Interpol
- Nuclear Smuggling Internatinal Technical Working Group (ITWG) Meeting 26-29 September 2006; Speyer
- Cooperation with new EU member states: e.g.
  Hungarian Academy of Sciences (joint analysis Nov. 2006)
  Slovakia (exercise May 2007; joint analysis early 2008)

Summary

Nuclear Forensics

involves Radiochemistry, Nuclear Physics, Reactor Physics, Material Science, Classical Forensics,…

provides clues on

- Intended Use
- Origin
- Last legal owner
- transport route

Helps preventing future diversion,
element of sustainability in
combating illicit trafficking of nuclear materials

May support prosecution

Methodology is also applicable in Nuclear Safeguards